

## S P E C I F I C A T I O N

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN that we, Yasunori SUZUKI, a subject of Japan and residing at Yokohama-shi, Kanagawa, Japan and Tetsuo HIROTA, a subject of Japan and residing at Minato-ku, Tokyo, Japan have invented certain new and useful improvements in

"TRANSMITTER"

and we do hereby declare that the following is a full, clear and exact description of the same; reference being had to the accompanying drawings and the numerals of reference marked thereon, which form a part of this specification.

## TRANSMITTER

### BACKGROUND OF THE INVENTION

#### Technical Field

5        The present invention relates to a radio base station transmitter having N transmission channels and, more particularly, to a radio base station transmitter adapted to suppress the creation of nonlinear distortions by power amplifiers.

#### Prior Art

10      A multi-port amplifier configuration has been proposed which permits reduction of the power consumption of N-channel amplifiers and implementation of their redundant configuration.

Figs. 1 and 2 show conventional multi-port amplifiers disclosed in Japanese Patent Application Laid-Open No. 10-209777.

15      Letting N represent an integer equal to or greater than 2, the multi-port amplifier comprises: an input side multi-port directional coupler 10 which divides and combines N input signals  $x_1, \dots, x_N$  into signals of N channels; N amplifiers  $33_1, \dots, 33_N$  which amplify the output signals of the N channels by parallel operation; an output side multi-port directional coupler 40 which divides and combines the outputs from the N amplifiers to provide N output signals  $u_1, \dots, u_N$ ; and linearizers  $20_1, \dots, 20_N$  each provided in the stage preceding one of the N amplifiers, for preimparting a compensating distortion to the signal of one of the N channels to cancel a nonlinear distortion which is created by the amplifier.

20      The input side digital multi-port directional coupler 10 can be formed by one or more  $\pi/2$  hybrids HB each having two input ports  $IP_1, IP_2$  and two output ports  $OP_1, OP_2$  as shown in Fig. 2A.   The relationships between two

inputs  $x_1, x_2$  and two outputs  $y_1, y_2$  of the  $\pi/2$  hybrid HB are expressed by the following equation.

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} x_1 + jx_2 \\ jx_1 + x_2 \end{bmatrix} \quad (1)$$

where the complex number  $x$  represents a  $\pi/2$  phase shift. That is, the signal  
 5  $x_1$  to the first input port  $IP_1$  is divided into two, one of which is output to the first output port  $OP_1$  of the original channel in phase with the input signal  $x_1$  and the other of which is output to the second output port  $OP_2$   $\pi/2$  out of phase with the input signal  $x_1$ . Similarly, the input signal  $x_2$  to the second input port  $IP_2$  is divided into two, one of which is output to the second output port  $OP_2$  of  
 10 the original channel in phase with the input signal  $x_2$  and the other of which is output to the second output port  $OP_1$   $\pi/2$  out of phase with the input signal  $x_2$ .

Setting a matrix  $T_1$  to

$$T_1 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \quad (2)$$

a four-port (4 inputs, 4 outputs) directional coupler can similarly be formed by  
 15 four  $\pi/2$  hybrids as depicted in Fig. 2B. The input and output signals can be expressed the following relationships.

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} T_1 & jT_1 \\ jT_1 & T_1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j & j & -1 \\ j & 1 & -1 & j \\ j & -1 & 1 & j \\ -1 & j & j & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

$$= \frac{1}{\sqrt{2}} \begin{bmatrix} x_1 + jx_2 + jx_3 - x_4 \\ jx_1 + x_2 - x_3 + jx_4 \\ jx_1 - x_2 + x_3 + jx_4 \\ -x_1 + jx_2 + jx_3 + x_4 \end{bmatrix} \quad (3)$$

where the coefficient -1 of  $x$  represent the opposite phase and  $j$  the  $\pi/2$  phase

shift.

In general, setting  $N=2^n$ , an N-port directional coupler can be formed uniquely by  $n2^{n-1}$   $\pi/2$  hybrids, and its transformation matrix  $T_n$  can be expressed by the following equation using  $T_{n-1}$ .

$$5 \quad T_n = \frac{1}{\sqrt{2}} \begin{bmatrix} T_{n-1} & jT_{n-1} \\ jT_{n-1} & T_{n-1} \end{bmatrix} \quad (4)$$

Fig. 2C shows a modified form of the four-port directional coupler, in which the multi-port directional couplers 10 and 20 are connected in cascade and the outputs  $y_1, y_2, y_3$  and  $y_4$  from the first-stage directional coupler 10 are input to the second-stage directional coupler 40 to obtain the original input signals  $x_1, x_2, x_3$  and  $x_4$ . The matrix connection of the  $\pi/2$  hybrid forming such a directional coupler is called Butler's matrix.

The conventional multi-port amplifier of Fig. 1, which utilizes the distribution of sending power among the transmission channels, uniformly divides or distributes the input power of each channel by the input-side multi-port directional coupler 10 to the N channels. This permits reduction of the saturation output from each amplifier and reduction of the overall power consumption of the amplifiers of the N channels as compared with the power consumption in the case where amplifiers of N channels are each provided independently of the others. Furthermore, even if the amplifier of one of the N channels fails, the dividing of each input signal  $x_n$  (where  $n=1, \dots, N$ ) by the input-side multi-port directional coupler 10 to N channels ensures power amplification by the amplifiers of the other channels. That is, it is known that the multi-port amplifier itself has a redundant configuration. Moreover, the overall efficiency of the multi-port amplifier improves through compression of the required output backoff by the linearizers 20<sub>1</sub>, ..., 20<sub>N</sub>.

The conventional multi-port amplifier of Fig. 1 has a configuration in

which individual amplifiers  $33_1, \dots, 33_N$  of the multi-port amplifier are linearized. Each linearizer  $20_n$  is usually a predistorter since it is provided at the input side of each amplifier. In accordance with the input signal to the amplifier the predistorter linearizes its AM/AM conversion characteristic (an input amplitude-output amplitude characteristic) and AM/PM conversion characteristic (an input amplitude-output phase characteristic). The multi-port amplifier of Fig. 1 calls for the use of the predistorter which operates in the sending frequency band.

It is of prime importance to manufacture small and light-weight  
10 N-channel transmitters. In particular, an adaptive array transmitter needs to be provided with many independent transmission channels; therefore, each transmitter must be as compact as possible. Even if the Fig. 1 multi-port configuration with predistorters are used in  $N$  transmission channels, it is necessary to form the entire channel by analog circuitry. But difficulty is  
15 encountered in implementing the whole system by one digital signal processing circuit containing a modulator and to reduce the number of parts used. To afford a sufficiently high degree of isolation between the output ports of the input side digital multi-port directional coupler 10, its gain and phase deviations between channels need to be adjusted to be sufficiently  
20 smaller than predetermined values, and the manufacture of such multi-port directional couplers in large numbers requires a circuit configuration that permits simplification of such adjustments.

## SUMMARY OF THE INVENTION

25 The transmitter according to the present invention comprises:  
an input-side digital multi-port directional coupler for dividing and combining digital transmission signals of  $N$  channels by digital processing and

- for outputting N-channel signals to N transmission channels, respectively;
- predistorters inserted in said N transmission channels, respectively, for linearizing said N transmission channels;
- transmitting parts inserted in said N transmission channels, respectively,
- 5 for converting output signals from said predistorters to high-frequency signals of said N channels; and
- an output-side multi-port power combiner for dividing and combining said high-frequency signals of said N-transmission channels to output high-frequency transmission signals for said N transmission channels.

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## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing the configuration of a conventional multi-port amplifier;

Fig. 2A is a diagram explanatory of a  $\pi/2$  hybrid;

15 Fig. 2B is a block diagram showing the configuration of a four-port directional coupler;

Fig. 2C is a diagram explanatory of a cascade connection of directional couplers;

20 Fig. 3 is a block diagram illustrating a basic functional configuration of the transmitter according to the present invention;

Fig. 4 is a block diagram depicting a first embodiment of the transmitter according to the present invention;

Fig. 5 is a block diagram showing an example of the configuration of a transmitting part;

25 Fig. 6 is a block diagram showing an example of the configuration of a receiving part;

Fig. 7 is a block diagram depicting an example of the configuration of a

predistorter;

Fig. 8 is a block diagram depicting a second embodiment of the transmitter according to the present invention; and

5 Fig. 9 is a block diagram depicting a third embodiment of the transmitter according to the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 3 illustrates a basic functional configuration of the transmitter according to the present invention. The transmitter comprises: an input side 10 digital multi-port directional coupler 13 which divides and combines input digital signals of N channels to provide output signals of N channels; predistorters 21<sub>1</sub>, ..., 21<sub>N</sub> which impart compensating distortions to the N-channel output signals, respectively; digital-to-analog (DA) converters 22<sub>1</sub>, ..., 22<sub>N</sub> which convert the outputs to analog signals; transmitting parts 30<sub>1</sub>, ..., 15 30<sub>N</sub> which output the outputs from the DA converters as high-frequency signals; and an output side multi-port directional coupler 40 which divides and combines the outputs from the N-channel transmitting parts and sends N-channel high-frequency signals to N antennas (not shown), respectively.

As will be seen from the above, in the present invention the signal 20 processing by the input side digital multi-port directional coupler 13 and the predistorters 21<sub>1</sub>, ..., 21<sub>N</sub> is digital processing. By performing the function of the multi-port directional coupler 13 through digital processing, it is possible to achieve characteristics of the multi-port directional coupler with ideal gain and phase deviations.

25 In the following description, letting discrete time t be represented by t=mT, where T is the sample period T [sec] of a digital signal and m is a positive number, and letting the input signal x<sub>n</sub>(m) of an nth channel be

represented by a complex amplitude, the input signal to the input side digital multi-port directional coupler 13 is expressed by the following matrix.

$$\mathbf{X}(m) = (x_1(m)x_2(m), \dots, x_N(m))^T \quad (5)$$

where  $T$  represents a transposition. The input signal  $\mathbf{X}(m)$  is transformed by

- 5 the N-channel input side digital multi-port directional coupler 13 through use  
of Eq. (4) to an output signal  $\mathbf{Y}(m)$  as given by the following equations.

$$\mathbf{Y}(m) = T_n \mathbf{X}(m) \quad (6)$$

$$\mathbf{Y}(m) = (y_0(m)y_1(m), \dots, y_{N-1}(m))^T \quad (7)$$

Letting  $F$  represent a waveform transformation matrix of predistorters  $21_1, \dots,$

- 10  $21_N$ ,  $\mathbf{Y}(m)$  is transformed to  $\mathbf{Z}(m)$ .

$$\mathbf{Z}(m) = F(\mathbf{Y}(m))\mathbf{Y}(m) \quad (8)$$

$$\mathbf{Z}(m) = \begin{bmatrix} f(y_0(m)) & 0 & 0 & 0 \\ 0 & f(y_1(m)) & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & f(y_{N-1}(m)) \end{bmatrix} \begin{bmatrix} y_0(m) \\ y_1(m) \\ \vdots \\ y_{N-1}(m) \end{bmatrix} \quad (9)$$

The signal  $\mathbf{Z}(m)$  is used to perform processing in the input side digital multi-port directional coupler 13 and the predistorters  $21_1, \dots, 21_N$  by digital signal processing. Let  $\mathbf{Z}(t)$  represent a matrix of analog signals converted by the DA converters  $22_1, \dots, 22_N$  from the signal  $\mathbf{Z}(m)$ . Respective elements of the signal matrix  $\mathbf{Z}(t)$  are subjected to frequency conversion to the transmission frequency band and power amplification in the transmitting parts  $30_1, \dots, 30_N$ . The power-amplified signals of  $N$  channels are transformed by the output side multi-port directional coupler 40 to transmission signals  $\mathbf{U}(t) = (u_1(t), \dots, u_N(t))$ .

The predistorters  $21_1, \dots, 21_N$  monitor the amplified output signals and adaptively update the coefficients of the waveform transformation matrix  $F$  by digital processing so as to achieve predetermined nonlinear distortion

characteristics.

The production of the signal  $Z(m)$  by the above processing allows complete elimination of imperfection of the operating characteristic of the input side multi-port directional coupler 13 formed by analog circuitry.

- 5 Further, it is possible to perform generation of the signals  $X(m)$  to  $Z(m)$  by digital signal processing. Since the above-described digital signal processing can be achieved by such software as DSP (Digital Signal Processor), the circuit configuration by the present invention can be implemented with more ease than the conventional configuration analog circuitry. Besides, since the input
- 10 side multi-port directional coupler, which is formed by an analog circuit in the prior art, is implemented by digital signal processing, the gain and phase deviations between the output ports can be reduced to zero. Zeroing the gain and phase deviations in the analog circuit configuration is impossible in terms of circuit fabrication accuracy. Accordingly, digital signal processing permits
- 15 simplification of the circuit adjustment as compared with the conventional analog circuit configuration.

## FIRST EMBODIMENT

- Fig. 4 illustrates the configuration of a first embodiment of the
- 20 transmitter according to the present invention.

The transmitter comprises: encoders  $12_1, \dots, 12_N$  of  $N$  channels; an input side digital multi-port directional coupler 13; predistorters  $21_1, \dots, 21_N$ ; quadrature modulators  $23_1, \dots, 23_N$ ; DA converters  $22_1, \dots, 22_N$ ; transmitting parts  $30_1, \dots, 30_N$ ; an output side multi-port directional coupler 40; receiving parts  $50_1, \dots, 50_N$ ; and analog-to-digital (AD) converters  $60_1, \dots, 60_N$ .

The encoders  $12_1, \dots, 12_N$  perform QPSK (Quadrature Phase Shift Keying) or similar encoding of a transmission digital signal sequence provided

to input terminals  $11_1, \dots, 11_N$ .

The input side digital multi-port directional coupler 13 inputs thereto complex signals of  $N$  channels and outputs complex signals of  $N$  channels.

The processing in the input digital multi-port directional coupler 13 calculates

- 5 Eq. (6) through use of the matrix defined by Eqs. (4) and (5). That is, the input side digital multi-port directional coupler 13 performs processing which multiplies the input signal matrix by the transformation matrix  $T_n$  starting at the left-hand side. The complex output signals of the respective channels  $y_1, \dots, y_N$  from the input side digital multi-port directional coupler 13 are fed to
- 10 the predistorters  $21_1, \dots, 21_N$ , respectively.

Each predistorter  $21_n$  (where  $n=1, \dots, N$ ) linearizes gain and phase characteristics of the signal of the corresponding channel by preimparting thereto a compensating distortion which cancels the nonlinear distortion generated by a power amplifier (Fig. 5, described later on) in the transmitting part  $30_n$ . The configuration of the predistorter  $21_n$  is a conventional look up table type or cuber distortion compensating type based on a power series model. The output signal from each predistorter  $21_n$  is subjected to quadrature modulation by digital signal processing in the quadrature modulator  $23_n$ . The output signal from the quadrature modulator  $23_n$  is converted by the DA converter  $22_n$  to an analog signal, which is provided to the transmitting part  $30_n$ .

For example, as identified generally by 30 in Fig. 5, each transmitting part  $30_n$  comprises: a frequency up-converting part 31 made up of a band-limiting low-pass filter 31A, a mixer 31B and a local oscillator 31C; a band-pass filter 32; and a power amplifier 33. In the transmitting part 30 the AD converter output signal is up-converted by being mixed with a high-frequency (RF) carrier signal generated by the local oscillator 31C, and a

signal of the RF transmission frequency band is extracted by the band-pass filter 32 and subjected to power amplification by the power amplifier 33. The power-amplified high-frequency transmission signal is transmitted via an antenna 42<sub>n</sub>. For example, as identified generally by 50 in Fig. 6, each 5 receiving part 50<sub>n</sub> comprises: a detecting part 51 made up of an attenuator 51A, a mixer 51B and a local oscillator 51C; a band-pass filter 52; and a control part 53.

As depicted in Fig. 6, in each receiving part 50<sub>n</sub> a portion of the power of the output signal from the transmitting part 30<sub>n</sub> of the corresponding channel 10 is detected by the mixer 51B and the local oscillator 51C via the attenuator 51A, and the detected signal is applied to the band-pass filter 52 to extract the distortion component generated by the power amplifier 33. Based on the extracted distortion component, the control part 53 generates a correcting signal, which is provided to the AD converter 61<sub>n</sub> (Fig. 4). The correcting 15 signal converted by the AC converter 61<sub>n</sub> to digital form is applied to the predistorter 21<sub>n</sub> to adjust its gain and phase characteristics to minimize the above-mentioned extracted distortion component, providing predetermined linearity of the transmitting part 30<sub>n</sub>.

Fig. 7 illustrates in block form an example of the predistorter 21<sub>n</sub> 20 (identified by 21). A wide variety of predistorters have already been proposed; the predistorter of this example is a digital predistorter using a power series model. The illustrated predistorter is configured to add together signals from a delay path which passes therethrough the fundamental wave component of the transmission signal, and on a path for generating an 25 odd-order distortion based on power series. That is, the predistorter 21 of this example is made up of a delay part 21A, a distortion generator 21B, a phase adjuster 21C, a gain adjuster 21D and an adder 21E. The fundamental wave

component of the transmission signal is fed to the adder 21E via the delay part 21A wherein it is delayed by the same time interval as the delay time of the distortion generating path. The distortion generator 21B generates a power series-based odd-order distortion, for example, third-order distortion, of the transmission signal. This odd-order distortion is adjusted in phase by the phase adjuster 21C and then adjusted in gain by the gain adjuster 21D, thereafter being added to the fundamental wave component by the adder 21E. The adder output is provided as the output from the predistorter 21 to the transmitting part 30<sub>n</sub> via quadrature modulator 23<sub>n</sub> and the DA converter 22<sub>n</sub> of the corresponding channel. Incidentally, the distortion generator may be configured to generate the third-, fifth-, or seventh-order distortion, or a desired combination of them.

By the phase and gain correcting signals provided thereto via the AD converter 60<sub>n</sub> (Fig. 4) from the control part 53 of the receiving part 50, the phase adjuster 21C and the gain adjuster 21D are adjusted to adjust the phase and gain of the odd-order distortion. The correcting signals provide coefficients for adjusting the phase adjuster 21C and the gain adjuster 21D, and define the waveform transformation matrix  $\mathbf{F}$  of the predistorter in Eqs. (8) and (9). The control part 53 may also be implemented by digital signal processing. In such an instance, each AD converter 60<sub>n</sub> in Figs. 4 and 8 is inserted between the band-pass filter 52 and the control part 53 in the receiving part 50<sub>n</sub> of Fig. 6 to convert the distortion component extracted by the band-pass filter 52 to a digital signal, and the control part 53 generates a digital correcting signal based on the digital distortion component.

In the Fig. 4 embodiment the encoders 12<sub>1</sub>, ..., 12<sub>N</sub> to the quadrature modulators 23<sub>1</sub>, ..., 23<sub>N</sub> are implemented by integrated digital signal processing. For example, in the case of a digital signal processing system

which operates in real time, the functions of the encoders  $12_1, \dots, 12_N$  to the quadrature modulators  $23_1, \dots, 23_N$  can be implemented as software. It is also possible to implement the functions of the encoders  $12_1, \dots, 12_N$  to the quadrature modulators  $23_1, \dots, 23_N$  by use of such hardware logic as FPGA

- 5 (Field Programmable Gate Array). This embodiment permits programmable implementation of the functions of the encoders  $12_1, \dots, 12_N$  to the quadrature modulators  $12_1, \dots, 23_N$ , and allows resetting of their functions adaptively or according to the circumstances. Accordingly, it is possible to cope with a plurality of modulation schemes and a plurality of predistortion schemes by  
10 use of the same DSP or FPGA hardware configuration. The input side digital multi-port directional coupler 13 and the predistorters  $21_1, \dots, 21_N$  may also be implemented by independent control programs. Besides, the control programs for the input side multi-port directional coupler 13 and the predistorters  $21_1, \dots, 21_N$  may be implemented by a single controller.

- 15 In the conventional multi-port amplifier configuration the input side digital multi-port directional coupler 13 and the output side multi-port directional coupler 40 are both implemented by analog circuits. The present invention implements the input side digital multi-port directional coupler 13 by digital signal processing as expressed by Eqs. (5) and (6). This eliminates the  
20 need for adjusting the gain and phase deviations between respective channels to be smaller than design values so as to provide a predetermined or greater degree of isolation between the output ports of the input side multi-port directional coupler as required in the prior art. That is, the present invention ensures complete isolation between the output ports of the input side directional coupler without any adjustment and hence enables the gain and phase deviations to be made zero. Accordingly, the present invention needs  
25 only adjustment of the output side multi-port directional coupler and provides

an increased degree of isolation of the multi-port configuration by less adjustment than in the prior art.

## SECOND EMBODIMENT

5 Fig. 8 illustrates in block form a second embodiment of the transmitter according to the present invention.

The illustrated transmitter comprises: quadrature modulators  $14_1, \dots, 14_N$  for quadrature modulation of input digital IQ signals; an input side digital multi-port directional coupler 13; predistorters  $21_1, \dots, 21_N$ ; DA converters  $22_1, 10 \dots, 22_N$ ; transmitting parts  $30_1, \dots, 30_N$ ; an output side multi-port directional coupler 40; receiving parts  $50_1, \dots, 50_N$ ; and AD converters  $60_1, \dots, 60_N$ . Each transmitting part  $30_N$  has the afore-mentioned configuration of Fig. 5, each receiving part  $50_N$  has the afore-mentioned configuration of Fig. 6, and each predistorter  $21_N$  has the afore-mentioned configuration of Fig. 7. This 15 embodiment is identical in construction with the Fig. 4 embodiment except the above.

This embodiment differs from the first embodiment in that the input digital multi-port directional coupler 13 and the predistorters  $21_1, \dots, 21_N$  perform processing of the digital signals  $x_1, \dots, x_N$  subjected to quadrature 20 modulation by the quadrature modulators  $14_1, \dots, 14_N$ . This embodiment is identical in operation and effect with the first embodiment. The configurations of the first and second embodiments implement the input side digital multi-port directional coupler 13 and the predistorters  $21_1, \dots, 21_N$  through digital signal processing, thereby permitting simplification, 25 miniaturization and weight reduction of the device configuration as compared with the conventional multi-port configuration.

### THIRD EMBODIMENT

Fig. 9 illustrates in block form of the Fig. 8 embodiment. While the first and second embodiments have been described to implement the predistorters  $21_1, \dots, 21_N$  by digital signal processing, they may also be formed by analog circuits as depicted in Fig. 9. In this case, the predistorters  $21_1, \dots, 21_N$  are inserted between the DA converters  $22_1, \dots, 22_N$  and the transmitting parts  $30_1, \dots, 30_N$ , respectively, and the distortion components extracted in the receiving parts  $50_1, \dots, 50_N$  are applied as correcting signals in analog form to the predistorters  $21_1, \dots, 21_N$ , respectively. In this embodiment, since the predistorters  $21_1, \dots, 21_N$  are formed by analog circuits, the transmitter configuration becomes larger than in the case of the Fig. 8 embodiment, but digital processing in the input side digital multi-port directional coupler 13 produces the intended effect.

In the first, second and third embodiments adaptive array antenna or sector antenna can be used as each of the antennas  $42_1, \dots, 42_N$  which are supplied with the output from the output side multi-port directional coupler 40. Further, a duplexer or switch commonly used in radio stations may also be provided between the output side multi-port directional coupler 40 and each of the antennas  $42_1, \dots, 42_N$  so that a receiver (not shown) is used also as an antenna.

### EFFECT OF THE INVENTION

As described above, according to the present invention, the implementation of the input-side multi-port directional coupler and the predistorters by digital signal processing produces such effects as (1) miniaturization of the transmitter and (2) facilitation of adjustment of the multi-port configuration.